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Trends of Air Pollutants in Colombo City and Relationship with Meteorological Variables

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Abstract: Colombo, the commercial capital of Sri Lanka, has to deal with air pollutants such as Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), Particulate matter ($PM_{2.5}$ and PM_{10}). The main objective was to study the trends of NO_2 and SO_2 concentrations during the period 2013-2019 and predict the future air quality of Colombo by modelling the monthly time series of those pollutants. The data used in this research was secondary, obtained from the National Building Research Organization (NBRO) and the Department of Meteorology of Sri Lanka. The SO_2 and NO_2 exponential smoothing models fitted had R- squared values of 66.40% and 68.90% respectively. Significant correlation results were obtained between the predicted (2020-2021) and the observed values. The NO_2 levels displayed a significant correlation ($r = 0.86$, $p < 0.05$). The multiple regression models fitted for NO_2 and SO_2 with the weather parameters indicated a good fit. A comparison of air pollutant levels recorded before the pandemic period (2013 - 2019) with the air pollutant levels after the pandemic (2020 - 2021) had a significant difference ($p < 0.05$). Statistically significant negative correlations were found between SO_2 levels with relative humidity ($r = -0.27$; $p < 0.05$) and between NO_2 levels with temperature ($r = -0.23$; $p < 0.05$), and relative humidity ($r = -0.36$; $p < 0.05$). Similarly, Air Quality Index (AQI) values determined from $PM_{2.5}$ showed a significant negative correlation with rainfall, relative humidity, and wind speed ($p < 0.05$) while AQI values of PM_{10} showed a significant negative correlation with rainfall and relative humidity ($p < 0.05$). Thus, increased levels of meteorological variables such as precipitation, humidity, and wind speed seem to reduce the atmospheric concentrations of the above pollutants.

Keywords: Air Pollution, Time Series Modelling, Forecasting

INTRODUCTION

Since ancient times, environmental pollution has played a critical role in human wellbeing. Air pollution has both long and short term effects on human health. Colombo, located in the Western coast, south of the Kelani river is the commercial capital of Sri Lanka. This city deals with air pollutants such as Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), and Particulate matter ($PM_{2.5}$ and PM_{10}) mainly released by anthropogenic activities [1]. This is further tested in the current study by comparing the air pollution patterns against policy- and other decisions taken in the country during the study period.

The main objective of the study is to observe the trend of NO_2 and SO_2 concentrations and predict the future air quality of Colombo by modelling the time series of monthly NO_2 and SO_2 from the year 2013 to 2019. Although air pollution in Colombo was studied previously [1,2], the chosen period was never analysed in any study. Another objective is to determine the relationship between NO_2, SO_2 concentrations, and AQI values with meteorological variables. The results of this study will immensely support the better management of the future urbanization of the city in par with pollution control and mitigation.

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MATERIALS AND METHODS

The data used in this research were secondary, obtained from NBRO and the Department of Meteorology of Sri Lanka. Monthly averages of NO_2 and SO_2 concentrations covering the period 2013-2019 were modelled using the time series analysis, and the future values were forecasted with a 95% confidence interval. The accuracy of the models was tested using the Ljung- Box test. Pearson correlation was used to test the validity of the models by comparing the observed and predicted values of the air pollutants for the years 2020 and 2021. The dataset of NO_2 and SO_2 over the period 2013 to 2019 was also fitted with appropriate trendlines to study the trends of the air pollutants.

The levels of NO_2 and SO_2 over the period 2013 to 2021 were regressed with the weather parameters of the same period as the independent variables. To address the effect of the pandemic on the levels of air pollutants, an indicator variable was added to the model, and the collinearity between these variables was studied using the variance inflation factor (VIF). To further increase the model performance, 20% of the dataset was randomly removed and those gaps were filled with the fitted values from the multiple regression.

Two sample t-tests were used to compare the air pollutant levels and AQI values between different monsoon periods. The AQI was calculated for $PM_{2.5}$ and PM_{10} using the formula prescribed by the United States Environmental Protection Agency [3].

One sample t-test was used to determine whether the mean of the AQI values is significantly different from the ambient air quality standards of National Environmental Act No. 47 of 1980. Correlation analyses were used to study the relationship of each air pollutant and AQI values with wind speed, rainfall, relative humidity, and temperature.

RESULTS AND DISCUSSION

According to the time series analyses, exponential smoothing models were observed to show the best fit for both monthly SO_2 and NO_2, in forecasting future values until the end of 2021(Figures 1 and 2).

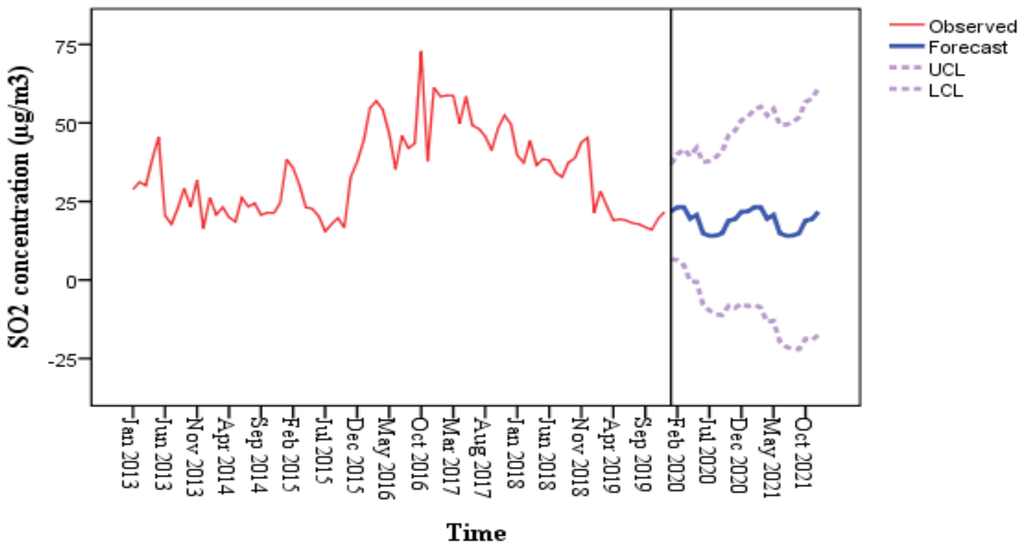

Figure 1. Forecasted values for Sulphur dioxide (SO_2) levels in Colombo based on time series analyses (2013-2019); Observed values of SO_2 are shown by the red line, forecasted values of SO_2 are shown by the blue line, Upper & Lower Confidence Levels (UCL & LCL) are depicted by dotted violet lines.

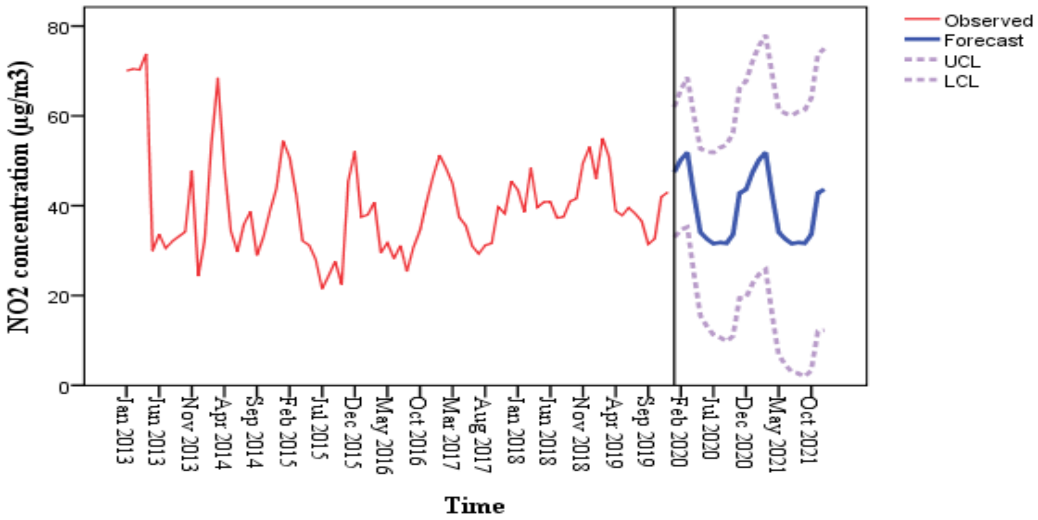

Figure 2. Forecasted values for Nitrogen dioxide (NO_2) levels in Colombo based on time series analyses (2013-2019); Observed values of NO_2 are shown by the red line, forecasted values of NO_2 are shown by the blue line, Upper & Lower Confidence Levels (UCL & LCL) are depicted by dotted violet lines.

The SO_2 and NO_2 exponential smoothing models fitted had stationary R-squared values of 66.40% and 68.90% respectively. The Ljung- Box tests showed a p-value greater than 0.05, thus making those models the best fitted.

The correlation results comparing the observed (2020 - 2021) with the predicted values showed that the SO_2 levels were not significantly correlated ($r = 0.40$, $p = 0.13$), whereas the observed and predicted NO_2 levels displayed a significant correlation ($r = 0.86$, $p = 0.00$).

The overall trends of the SO_2 and NO_2 datasets over the period 2013 – 2019 are depicted by Moving Average (MA) trendline and quadratic trendlines in Figures 3 and 4 respectively.

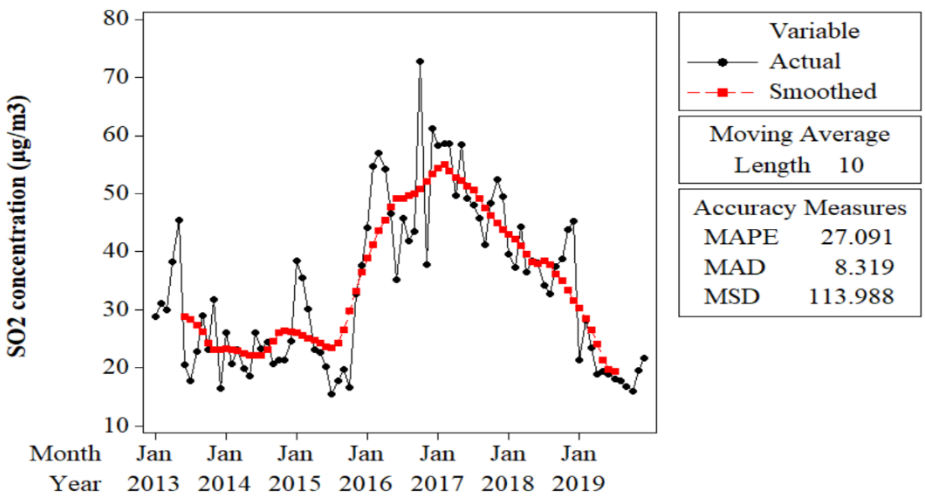

Figure 3. Moving Average (MA) Trendline for SO_2 from 2013 to 2019; The actual values are depicted by the black line with circles and the fitted smoothed trendline is depicted by dotted red lines with squares, Mean Absolute Percentage Error (MAPE), Median Absolute Deviation (MAD), Mean Squared Deviation (MSD).

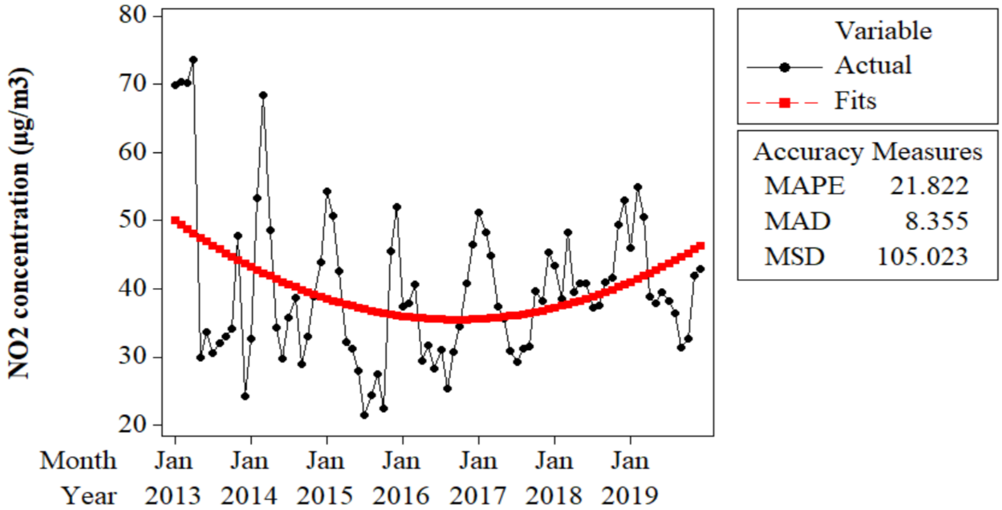

Figure 4. Quadratic trendline for NO_2 for the period 2013-2019. The actual values are depicted by the black line with circles and the fitted quadratic trendline is depicted by dotted red lines with squares, Mean Absolute Percentage Error (MAPE), Median Absolute Deviation (MAD), Mean Squared Deviation (MSD).

Both the MA and quadratic trendline have low Mean Absolute Percentage Error (MAPE) measures, meaning that the fitted values are different from the actual values by 27. 10% and 21.80% respectively.

The multiple regression models fitted for NO_2 (Table 1) and SO_2 (Table 2) indicated a good fit with an adjusted R^2 of 55.1% and 42.5% respectively.

Table 1. Regression Analysis of NO_2 with weather parameters for the period 2013 to 2021 in Colombo

Predictor	Coef	SE Coef	T	P	VIF
Constant	305.40	48.64	6.28	0.00	
Temperature (°C)	-3.77	1.41	-2.68	0.01	1.1
Relative Humidity (%)	-1.73	0.33	-5.33	0.00	1.2
Windspeed (km/h)	-3.57	0.93	-3.85	0.00	1.6
Covid-19 situation	-28.21	3.30	-8.56	0.00	1.5

Table 2. Regression Analysis of SO_2 with weather parameters for the period 2013 to 2021 in Colombo

Predictor	Coef	SE Coef	T	P	VIF
Constant	189.65	43.90	4.32	0.00	
Temperature (°C)	1.05	0.41	2.52	0.01	2.1
Relative Humidity (%)	-2.02	0.57	-3.55	0.00	2.1
Covid-19 situation	-27.90	3.53	-7.91	0.00	1.0

The indicator variable used for "Covid-19 Situation" had a p-value less than 0.05, indicating that there was a significant difference in air pollutant levels before (2013 – 2019) and during the pandemic period (2020-2021). The variance inflation factors about 2 or less show a moderate correlation between the independent variables. Removal of 20% of the variables resulted in increased model performance in NO_2 with a R^2 value of 60.40%. However, the same analysis yielded in model performance was only 37% for SO_2.

The study area considered does not have many industries, but generally experiences a high volume of vehicles. From the latter part of 2015 to early 2017, there is an upward trend in SO_2 most probably due to the increased volume of small cars on the road with reduced prices based on tax amendments in 2015. The 2017 budget again revised the tax, increasing the prices of such vehicles [4]. The downward trend of SO_2 from 2017 could be attributed to the introduction of low-sulfur fuel (i.e. Lanka Super diesel Euro 4) in 2018.

The increasing trend of NO_2 from 2016 to 2019 could be due to the overall increased number of personal vehicles on the road and the introduction of ride-hailing taxi services such as PickMe and Uber in 2015 [5] in Sri Lanka which could be the reason for the higher levels of NO_2 recorded in those years.

The NO_2 levels in the atmosphere during the Southwest monsoon are significantly lower than those during the Northeast Monsoon period ($p < 0.05$). This could be attributed to the higher amount of rainfall during the Southwest monsoon than the Northeast monsoon period [6]. The PM levels in the atmosphere too were significantly varying between different monsoonal periods. The SO_2 levels did not display such variations between the two monsoonal periods.

Though the mean levels of PM in the atmosphere are significantly lower than the standards prescribed by the National Environmental Act (NEA; $p < 0.05$), the standards in Sri Lanka have been set to higher limits than the World Health Organization (WHO) prescribed limits [7].

The SO_2 levels are negatively correlated with relative humidity ($r = -0.27$; $p < 0.05$) and the NO_2 levels are negatively correlated with temperature ($r = -0.24$; $p < 0.05$) and relative humidity ($r = -0.36$; $p < 0.05$). The AQI values based on $PM_{2.5}$ displayed a significant negative correlation with rainfall ($r = -0.62$; $p < 0.05$), relative humidity ($r = -0.40$; $p < 0.05$) and windspeed ($r =-0.11$; $p < 0.05$). The AQI values of PM_{10} displayed a significant negative correlation with rainfall ($r = -0.21$; $p < 0.05$) and relative humidity ($r = -0.44$; $p = < 0.05$). Thus, increased levels of meteorological variables such as precipitation, humidity, wind speed seem to reduce the atmospheric concentrations of the above pollutants.

It can be concluded that the findings clearly show the influence of anthropogenic activities on the air pollutant levels. An increase in relative humidity could lead to a reduction in levels of NO_2, SO_2 in the air and the overall AQI. With high levels of precipitation, the Southwest monsoon recorded lower levels of air pollutants. The predicted values of air pollutants can be used in making important management decisions such as decisions based on traffic regulation during different times of the year and assessing the requirement of new roads to reduce traffic congestion in Colombo urban area. While economic development had to be considered in policy initiatives, attention should also be paid to environmental damage spurred by the proposed actions. With the changing climate and weather patterns, sustainable solutions must be adopted to solve problems rising with rapid urbanization. The implications of current and future developmental activities of Colombo urban area on the ambient air quality need to be always monitored and suitable policy measures and regulatory actions should be instigated.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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